Monitoring the Green and Golden Bell Frog: current problems and an alternative approach

Trent D. Penman and Frank L. Lemckert

Forest Science Centre, Department of Primary Industries. PO Box 100, Beecroft, NSW. 2119. Australia.
Corresponding Author Email: TrentP@sf.nsw.gov.au

ABSTRACT

The Green and Golden Bell Frog *Litoria aurea* is the subject of a number of population monitoring studies to assess its long-term status. However, we question the value of standard monitoring strategies for this species. The numbers of frogs detected at a single pond can be highly variable over time, creating significant variance in population estimates and so serious difficulties in statistically detecting population changes. The species is also believed to exhibit a metapopulation structure with natural levels of site extinctions balanced by site colonisations. Traditional monitoring would view site declines as serious impacts on the population, but they are insignificant if balanced by the colonisations. We believe that population estimates using site occupancy modelling may be a better method of monitoring Green and Golden Bell Frog populations. We explore this option, comparing it to traditional approaches, and consider that monitoring site occupancy should be time-effective and statistically more sensitive in detecting annual trends in populations. We recommend testing this approach further with a suitable data set to better determine whether Site Occupancy Modelling is a more sensitive means of monitoring Green and Golden Bell Frog populations.

Key words: Occupancy, ecological modelling, power analysis, *Litoria aurea*

Introduction

The Green and Golden Bell Frog *Litoria aurea* has undergone serious declines throughout its range since the late 1970s (Mahony 1999). The current populations remain almost exclusively in areas potentially or actually subject to many human influences (Pyke and White 1996), with many being centred around water bodies in urban areas or in modified rural landscapes (e.g. sandmining sites; Daly 1996). The Green and Golden Bell Frog is considered to be a colonising species, populating newly disturbed areas and declining in numbers as the site ages (Pyke and White 2001). An important issue is whether a specific human activity is leading to further declines or, alternatively, is the reason for the species' survival. Human activities may be creating suitable habitat and if activities are not continued declines may occur. Alternatively, these activities may be hastening declines by changing currently favourable habitat. Thus, monitoring Green and Golden Bell Frog populations is, in many cases, a high priority in order to determine if they are stable, increasing, or declining and if actions are required to assist their long-term maintenance. There have been a number of attempts to increase populations through habitat creation and suitable monitoring programs are essential in assessing the efficacy of habitat creation as well as the development of effective recovery strategies (DEC 2005).

One major requirement of any monitoring program is an ability to effectively detect changes in populations (de Solla *et al.* 2005; Pellet and Schmidt 2005). Traditional statistical methods for determining population parameters require repeated counts of populations, preferably with accurate estimates of population size (Krebs 1989). Common methods employed for amphibians include counts of calling males, visual encounter surveys to count numbers of individuals, and pit-traps (Heyer *et al.* 1994). When counts used to estimate population sizes vary greatly between surveys, the estimates of total population size will have wide confidence intervals. When this happens it is extremely difficult to determine if a large variation in numbers counted from one year to the next is a result of a change in numbers of frogs present, or the observer's ability to detect the frogs. Some computer programs such as MARK (http://www.warnercnr.colostate.edu/~gwhite/mark/mark.htm) (White and Burnham 1999) allow for the incorporation of co-variates into the analysis, which partially addresses this issue.

In this paper we examine the potential of Site Occupancy Modelling (MacKenzie *et al.* 2006) as an alternative monitoring approach for the Green and Golden Bell Frog. We explore the issues faced in developing effective monitoring programs for this species and assess the ability of different monitoring methods to overcome these issues. We do so by firstly examining the elements of Green and Golden Bell Frog biology that are of importance for estimating population sizes. We then consider how this knowledge fits in with the requirements for the currently used monitoring strategies and explore the sensitivity of statistical analysis to detect population changes. Finally, we explore the basic concepts of site occupancy modelling and its relevance and potential effectiveness in monitoring metapopulations and the Green and Golden Bell Frog.

Green and Golden Bell Frog Population Biology

Several elements of Green and Golden Bell Frog biology are of importance when developing population monitoring. In this section, we provide a brief summary of these elements, but refer readers to Pyke and White (2001) and Hamer and Mahony (2007) for a more complete review of the species' biology.

Green and Golden Bell Frogs have a distinct activity season lasting usually from September to April. Throughout this period male frogs attend breeding sites, calling when conditions are suitable (Pyke and White 2001). Female frogs migrate to breeding sites to lay eggs and spend only a few days per year engaged in this behaviour. Male and female frogs may attend several breeding sites in the same year and so concentrations of breeding individuals at any given site may change between surveys (Goldingay and Newell 2005a). Calling and egg-laying are generally tied to times during or immediately after rainfall in spring and summer. Hence, breeding activity depends on the weather and so can vary greatly through a season with little activity being evident on most days (Hamer and Mahony 2007). In "dry" years, calling and breeding may be limited to and scattered over a few weeks of time. A broad range of breeding and non-breeding sites can be used in an activity season by this species. The species has been recorded breeding in ephemeral pools and creeks, temporary pools, semi-permanent wetlands, large coastal swamps and farm dams (Cogger 2000). During the coldest months of the year, individual frogs are inactive and difficult to detect, apparently sheltering deeply within protected sites such as scree slopes, dense vegetation or under wood piles (Hamer *et al.* 2003). This distinct activity period allows for the separation of survey seasons or years, allowing for simple assessments to be made regarding changes over time.

When not undertaking breeding activity, individuals maintain activity areas close to or overlapping with a breeding site. Activity areas vary from less than 100 m^2 to at least 700 m^2, depending on the presence of suitable habitat types (breeding, shelter and foraging habitats). At these times individuals require and find shelter under a wide range of objects and spend their time feeding on a range of invertebrate and even vertebrate prey. Even larger movements are made occasionally, with individuals being found 1-2 km from the breeding site and even as far as 10 km away (Pyke and White 2001). Movements of this magnitude are probably not common, but data on this remains to be collected. Hamer *et al.* (2002) found however, that ponds isolated from suitable and occupied breeding sites by more than 500 m were unlikely to have this species present, suggesting that longer movements in that population were not common. Activity appears to be tied strongly to rainfall and so dry periods will see most or all animals hiding under shelter. These behaviours result in the species being observed in discrete localities that enhances our ability to effectively monitor the species as effort can be focused to these habitats.

The Green and Golden Bell Frog is considered to be a colonising species, readily moving into newly created or disturbed sites and often vacating these over time as the sites mature and become less suitable habitat (Pyke and White 2001; but see Goldingay and Newell 2005a). The suitability may be determined by the degree of vegetation and the associated shading of the site for the adults and tadpoles, or may be related to competition with other species of frogs that move into the site as it "matures". Loss of populations from sites then, is a natural and expected event over time if further disturbance does not occur. Traditional monitoring approaches consider extinction as a negative event even when it is balanced by a colonisation elsewhere.

Count Based Monitoring

Standard monitoring programs for frogs involve obtaining counts of selected populations on an annual basis and then comparing the counts to assess there are declines in the population(s) (e.g. Pierce and Gutzwiller 2004). This involves either counting the number of animals observed or the number of calling males through auditory surveys (see Zimmerman *et al.* 1994). Taking several counts within a year provides a mean number of animals or calling males and an estimate of the variance in numbers. These counts can then be compared statistically between years to determine if there is an increase or decline in the number of frogs present.

The obvious problem with this method for Green and Golden Bell Frogs (and frogs in general) is that the counts can and do vary enormously within a season, often from week to week and even day to day. Variation in numbers of visible animals or calling males is most often simply a result of changing weather conditions (Krupa 1994; Spieler and Linsenmair 1999; Lemckert 2001; Bulger *et al.* 2003; Penman *et al.* 2006). Unless surveys are timed to ensure counts are obtained in near identical weather conditions, large variations in counts are almost inevitable. For example, if counts in "good" conditions cannot be undertaken in one year or over one period of the year (due to climatic or logisitical constraints), no amount of other effort will be sufficient to produce comparable counts. This means that there is a relatively good chance of getting a reasonably large change in the animals observed even when there is no actual change in the number of animals present at sites.

To examine this, we conducted a simulation based on count data presented by Goldingay and Newell (2005a) from Yuraygir National Park using the R statistical packgage (see http://www.r-project.org/). In the first season (August 1998 – March 1999) the authors surveyed the site on 9 occasions at approximately 1-month intervals and recorded a mean of 12.8 frogs per survey with a standard deviation of 6.3. No other published data were available, however, based on our experience these values are consistent with survey results from other Green and Golden Bell Frog populations. Using this information we generated survey results using a normal distribution based on the mean and standard deviation listed above under scenarios of

5, 10, 20 and 50% annual declines in the mean (i.e. each year the population is x% less than the previous year). For each year, we used a simple t-test to compare the simulated survey results with those of time 0, i.e. the data from Goldingay and Newell (2005a). Each scenario was simulated 1000 times and the number of results significant at the p=0.05 level recorded.

After a single year, the simulations suggest that using the count method will result in a 65% chance of detecting a 50% decline in population size, a 7% chance for a 20% decline and less than 3% chance for detecting either a 5 or 10% decline (Figure 1). After five years of declines, these values increase to 100% for a 50% annual decline, 80% for a 20% annual decline, 26% for a 10% annual decline and only 7% for a 5% annual decline (Figure 1). These results indicate that the change in population size has to be catastrophic and over an extended time period to achieve a reasonable chance of detecting a significant drop in numbers. This suggests that when a statistically meaningful decline is detected it may easily be too late to take management actions to reverse the declines.

Capture-Recapture Monitoring

The second commonly used approach is to estimate the total adult population at a site by capture-mark-recapture (Goldingay and Newell 2005a,b). This usually involves capturing as many frogs at a site as possible, marking them individually, releasing them and then capturing as many frogs again as possible at later dates. Using a simple Peterson index (Krebs 1989), the population size can be estimated as the number of frogs marked in the first survey session divided by the proportion of animals captured in the second survey session that are marked. However, the highly variable and weather dependent behaviour of frogs (e.g. van de Mortel and Goldingay 1998; Lemckert 2001; Penman *et al.* 2006) means that captures also vary greatly between days leading to inaccuracy in estimates unless large amounts of effort are expended. We acknowledge that more complex (and potentially more accurate) techniques are available for estimating population size, however, the data required for such techniques are not available for the Green and Golden Bell Frog to simulate these approaches.

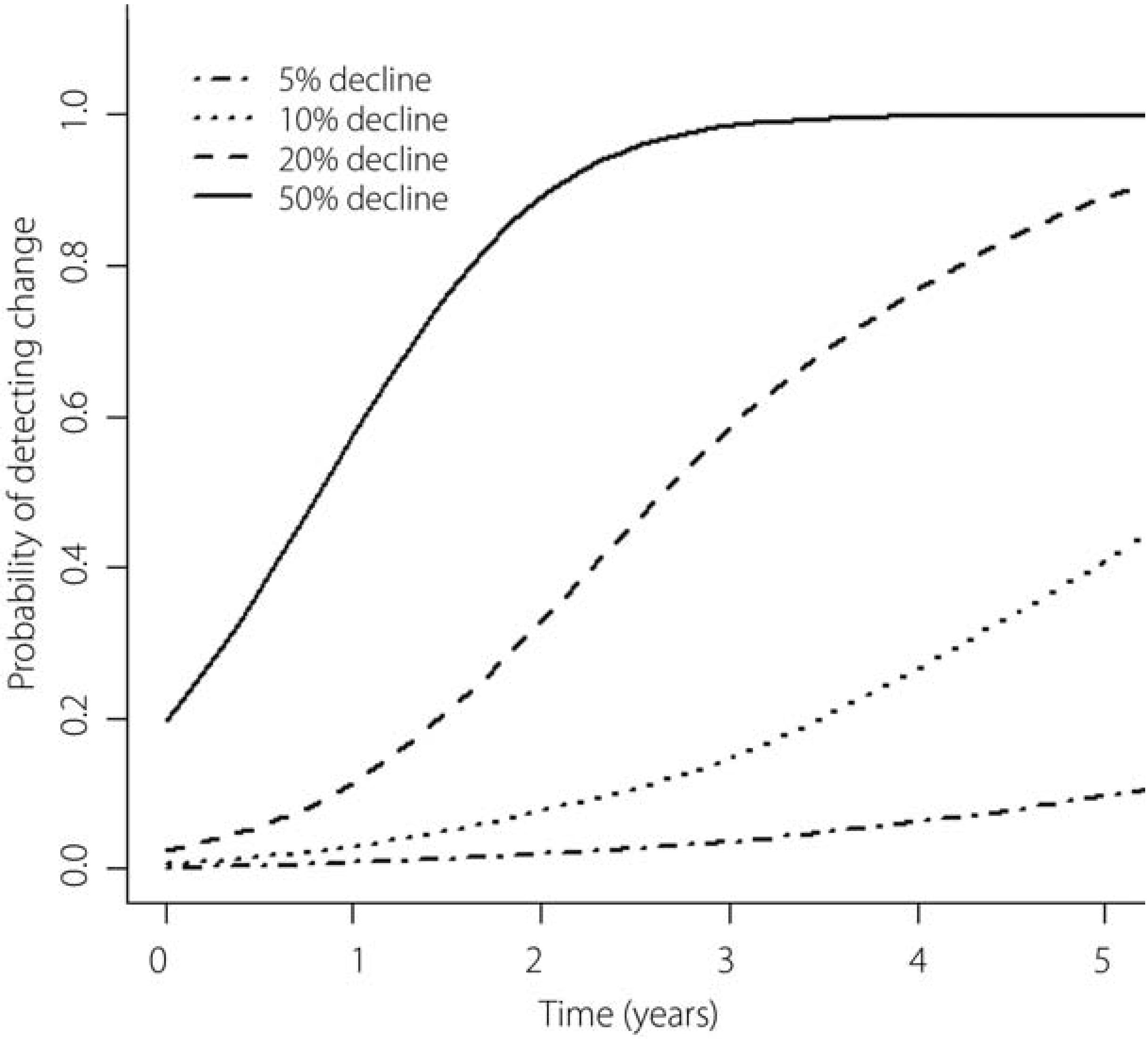

Figure 1. Results of the simulation of population declines based on data from Goldingay and Newell (2005a).

We simulated the accuracy of this method for a virtual population of bell frogs. The simulations were based on a population of 100 frogs and the assumptions of the Peterson Index, i.e. all animals have an equal chance of being caught and there is no mortality or recruitment between surveys. Simulations were conducted for initial captures of 30, 40, 50 and 60 frogs and captures in the second survey ranging from 20 to 100 at increments of 5. The proportion of recaptures was taken as a uniform distribution (equal probability of capture) between 0 and the # initial captures/# captures in the second survey. If the initial capture was greater than the total captured in the second survey, the distribution was taken between 0 and 1 (i.e. 100% recaptures). Results of the simulations are presented in Figure 2, with the average predicted population estimate and the average upper and lower confidence limits to those estimates based on 1000 simulations. Predictions from this technique do not become accurate until the sum of the number of frogs caught in the first survey session (F) and the number of frogs caught in the second survey session (S) exceeds the total number of frogs in the population (N), i.e. F+S>N. While either survey session does not need to be a single night, it is unusual for more than 20 frogs to be encountered at a site in any given night (Pyke and White 2001). To achieve accurate predictions of population size that will allow for the detection of changes in population size is likely to require at least three surveys in suitable climatic conditions per "survey session" and several more if conditions are sub-optimal, suggesting a minimum of six surveys for a population estimate. This makes this technique intensive and costly to conduct with few guarantees of success.

Simulations of population estimates have highlighted another important issue when attempting to apply this technique. When F+S<N, population estimates are not only highly variable, but also significantly higher values are provided for the population size (Figure 2). To our knowledge, in only two cases have researchers made the important effort to publish their population estimates for the Green and Golden Bell Frog. These studies by Goldingay and Newell (2005a, b) provided the best estimates given the time and resources available and acknowledged the uncertainty in these estimates. Several others studies have appeared in unpublished reports (e.g. AMBS 2000, 2001) and also have large confidence intervals around the mean suggesting an insufficient number of animals have been captured and predictions regarding population size may be over-inflated. From a

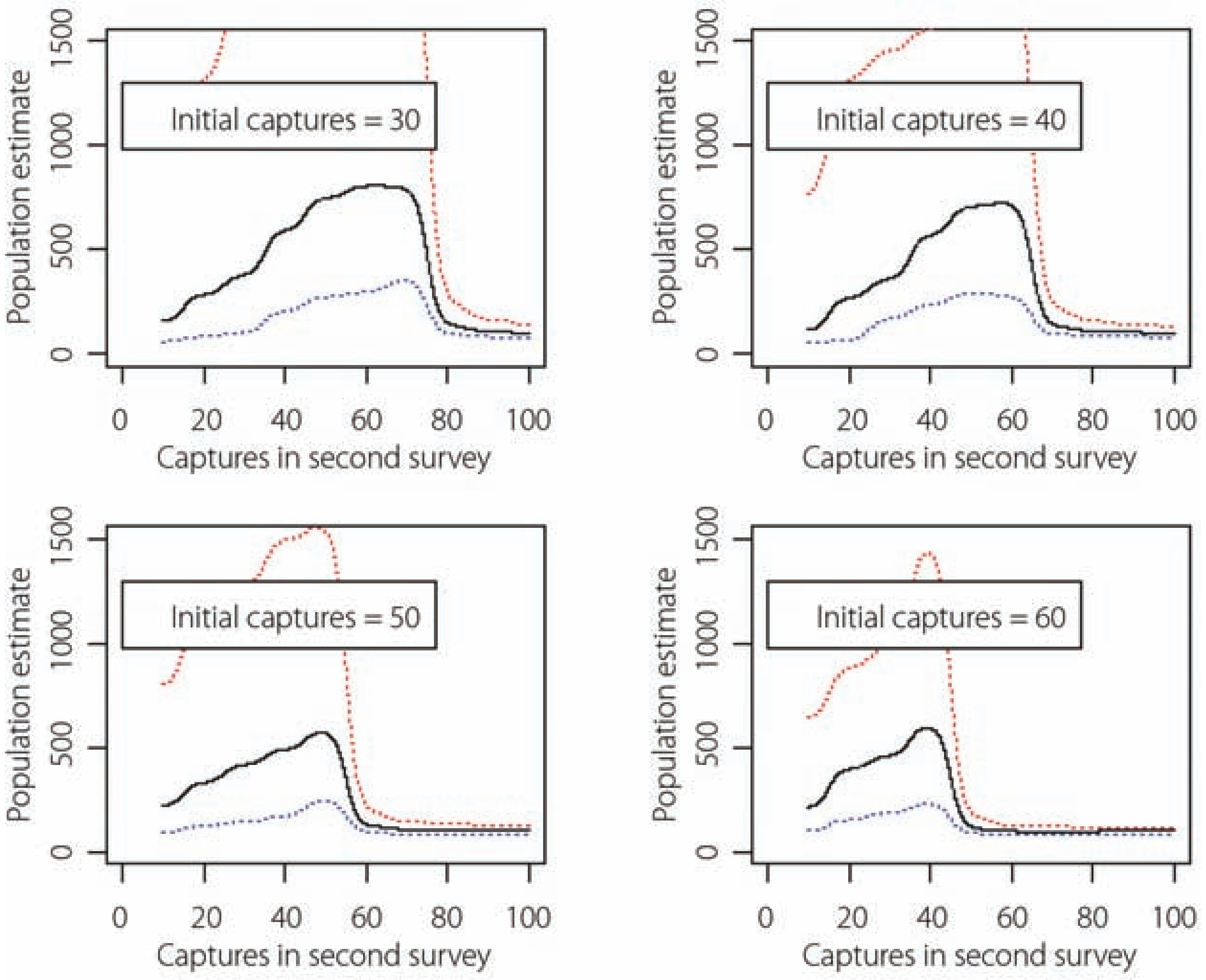

Figure 2. Population estimates based on initial captures of 30, 40, 50 and 60 green and golden bell frogs. Solid lines indicate the mean estimate based on 1000 simulations. Dotted lines indicate mean upper and lower estimates based on the 1000 simulations.

management and research perspective this is an extremely undesirable position particularly if the estimates in the reports were treated as being highly accurate population size estimates. Firstly, any change in population size cannot be reliably detected whether it is an increase or a decrease. Secondly, reporting of large population sizes provides an unrealistic view of the status of populations and of the species that could influence the urgency and nature of recovery actions for individual populations.

Site Occupancy Models

There has been considerable development in the field of detectability and site occupancy in recent years (e.g. MacKenzie *et al.* 2001, 2003; Wintle *et al.* 2004; Pellet and Schmidt 2005). These techniques are commonly being applied to development of fauna monitoring programs to ensure that land managers are able to maximise the output of the program and minimise costs. These models are based on meta-population theory and are ideally suited for monitoring programs that survey a number of clearly defined sites. Generally, the models are based on presence/absence data, however, models have been developed to incorporate count data if desired (e.g. Royle *et al.* 2005).

To estimate occupancy, software packages such as PRESENCE (see www.proteus.co.nz) simultaneously model detectability and occupancy to account for the issue of non-detection, i.e. a false negative (MacKenzie *et al.* 2006). Using a logistic regression framework, detectability can be modelled as varying between surveys, in relation to either survey-specific factors (e.g. rainfall, presence of other species, pond depth) and site-specific factors (e.g. pond size, distance to urban interface, disturbance variables). In contrast, occupancy is assumed to be constant within a given season and can therefore only be modelled in relation to site-specific factors and/or season. More complex models can be developed to model site-specific factors leading to either extinction or colonisation (MacKenzie *et al.* 2006). These models would be particularly relevant to a monitoring program for species in managed environments as the impact of management actions in a given season can be tested in the following seasons. Applying these models in a statistically rigorous manner will provide managers with better information on how to manage the species and provide scientists with greater understanding of the species' ecology and population dynamics.

The known biology of the Green and Golden Bell Frog appears to fit better into this approach to monitoring. Green and Golden Bell Frogs occupy relatively large numbers of ponds where they occur (AMBS 2000; Pyke and White 2001) and we can use these as distinct sites within a Site Occupancy Model. Sites within the model are not restricted to breeding sites and in the case of bell frogs could include soaks, drainage lines, temporary and ephemeral pools and wetlands, where these sites are regular shelter sites for individuals. The number of animals present is not important, just that they are present. Of greater importance is that this species does regularly attempt to colonise new sites and appears to disappear from old sites as they mature (part of being a colonising species). This appears to be the natural situation and may represent a metapopulation structuring of Green and Golden Bell Frog populations. Site occupancy modelling assesses the loss of these sites against balancing colonisations of previously unoccupied sites and considers the whole population of an area. Standard monitoring could see the decline and loss of site populations as serious problems without understanding the bigger picture. Furthermore, Site Occupancy Models address the issue of non-detections of the species when frogs are actually present and account for these in the modelling process, adding further to their rigor.

Conclusions

We believe that Site Occupancy Models hold considerable potential as means of monitoring larger populations of the Green and Golden Bell Frog, where there are many potential breeding and shelter sites available for use. We would like to carry out more effective simulations with a suitable data set to confirm our conclusions, but do not have available to us a suitable data set with which to do this. Published data are not suitable for simulations of Site Occupancy Models as they lack essential data on the number of visits to each individual site within an area and the number of presences and absences that were recorded for each site. Any simulation of such data would not be without bias and therefore not valid for a comparison of the other available techniques. Such datasets are available from monitoring programs at Homebush Bay (AMBS 2001), Koorogang Island (e.g. Hamer *et al.* (2002) describe a dataset that would be ideal), Kurnell, Hat Head and Port Kembla and we urge the holders of these data to try Site Occupancy Modelling and determine if it provides a more effective assessment of their data. Using this approach in a new monitoring program to test its efficacy also would be highly desirable, particularly where there are more (>15) potentially occupied sites that are being monitored using a formal monitoring program to detect the presence of individuals. We say this because we can demonstrate that current monitoring methods are highly insensitive to detecting changes in populations without very large amounts of effort and a degree of good luck. Managing this species, particularly where we are modifying habitats in an attempt to increase its numbers, requires us to have a statistically sensitive means of detecting population changes in realistic time frames. Current monitoring methods seem highly unlikely to do this and Site Occupancy Models seem likely to provide a much better approach.

Acknowledgments

We thank Ross Goldingay for his suggestions in writing this manuscript, Mike Mahony for comments on mark-recapture analysis and Forests NSW for their support in our ongoing work. Dave Hunter, Brad Law, Rod Kavanagh and an anonymous referee provided comments on an early draft of this manuscript.

References

Bulger, J.B., Scott, N.J and Seymour, R.B. 2003. Terrestrial activity and conservation of adult California red-legged frogs *Rana aurora draytonii* in coastal forests and grasslands. *Biological Conservation* **110,** 85-95.

Cogger, H.G. 2000. *Reptiles and Amphibians of Australia*. Reed Books Australia: Melbourne.

Daly, G. 1996. Some problems in the management of the Green and Golden Bell Frog *Litoria aurea* (Anuran: Hylidae) at Coomonderry Swamp on the South Coast of New South Wales. *Australian Zoologist* **30**: 233-236.

De Solla, S.A., Shirose, L.J., Fernie, K.J., Barrett, G.C., Brousseau, C.S. and Bishonp, C.A. 2005. Effect of sampling effort and species detectability on volunteer based anuran monitoring programs. *Biological Conservation* 121: 585-594.

Garrison, R.W. 1978. A mark-recapture study of imaginal *Enallagma cyathigerum* (Charpentier) and *Argiavivida* Hagen (Zygoptera: Coenagrionidae). *Odonatologica* 7: 223-236.

Goldingay, R.L. and Newell, D.A. 2005a. Aspects of the populations ecology of the green and golden bell frog *Litoria aurea* at the northern end of its range. *Australian Zoologist* **33**: 49-59.

Goldingay, R.L. and Newell, D.A. 2005b. Population estimation of the green and golden bell frog *Litoria aurea* at Port Kembla. *Australian Zoologist* **33:** 210-216

Hamer, A.J, Lane, S.J. and Mahony, M.J. 2002. Management of freshwater wetlands for the endangered green and golden bell frog (*Litoria aurea*): roles of habitat determinants and space. *Biological Conservation* **106**: 413-424.

Hamer, A.J., Lane, S.J. and Mahony, M.J. 2003. Retreat Site Selection during Winter in the Green and Golden Bell Frog, *Litoria aurea* Lesson. *Journal of Herpetology* **37**: 541-545

Hamer, A.J. and Mahony, M.J. 2007. Life history of an endangered amphibian challenges the declining species paradigm. *Australian Journal of Zoology* **55:** 79-88.

Krebs, C.J. 1989. *Ecological Methodology.* Harper and Row. New York, USA.

Krupa, J.J. 1994. Breeding biology of the Great Plains Toad in Oklahoma. *Journal of Herpetology* **28**: 217-224.

Lemckert, F. 2001. The influence of micrometeorological factors on the calling activity of the frog *Crinia signifera* (Anura, Myobatrachidae). *Australian Zoologist* **31**: 625-631.

MacKenzie, D.I, Nichols, J.D., Hines, J.E., Knutson, M.G. and Franklin, A.B. 2003. Estimating site occupancy, colonization and local extinction when a species is detected imperfectly. *Ecology* **84**: 2200-2207.

MacKenzie, D.I., Nichols, J.D., Lachman, G.B., Droege, S., Royle, J.A. and Langtimm, C.A. 2001. Estimating site occupancy rates when detection probabilities are less than one. *Ecology* **83**: 2248-2255.

MacKenzie, D.I., Nichols, J.D., Royle, J.A., Pollock, K.H., Bailey, L.L. and Hines, J.E. 2006. *Occupancy Estimation and Modelling: Inferring Patterns and Dynamics of Species Occurrence.* Elsevier, Sydney, Australia.

Mahony, M. 1999. Review of the declines and disappearances within the bell frog species group (*Litoria aurea* species group) in Australia. Pp. 109-30 in *Declines and Disappearances of Australian Frogs*, edited by A. Campbell. Environment Australia, Canberra.

Pellet, J. and Schmidt, B.R. 2005. Monitoring distributions using call surveys: estimating site occupancy, detection probabilities and inferring absence. *Biological Conservation* 123: 27-35.

Penman, T.D., Lemckert, F.L. and Mahony, M.J. 2006. Meteorological effects on the activity of the giant burrowing frog, *Heleioporus australiacus,* in south-eastern Australia. *Wildlife Research* **33**: 35-40.

Pierce, B.A. and Gutzwiller, K.J. 2004. Auditory Sampling of Frogs: Detection Efficiency in Relation to Survey Duration. *Journal of Herpetology* **38**: 495-500.

Pyke, G.H, and White, A.W. 1996. Habitat requirements for the Green and Golden Bell Frog *Litoria aurea* (Anura: Hylidae). *Australian Zoologist* **30:** 224-232.

Pyke, G.H. and White, A.W. 2001. A Review of the biology of the Green and Golden Bell Frog *Litoria aurea*. *Australian Zoologist,* **31**: 563-598.

Royle, J.A., Nichols, J.D. and Kery, M. 2005. Modelling occurrence and abundance of species when detection is imperfect. *Oikos* **110**: 353-359.

Salkeld, D. J. and Schwarzkopf, L. 2005. Epizootiology of blood parasites in an Australian lizard: a mark-recapture study of a natural population. *International Journal for Parasitology* **35**: 11-18.

Smith, T. D.. Allen, J., Clapham, P. J., Hammond, P. S., Katona, S., Larsen, F., Lien, J., Mattila, D., Palsbøll, P. J., Sigurjónsson, J., Stevick, P. T., and Øien, N. 1999. An ocean-basin-wide mark-recapture study of the North Atlantic humpback whale (*Magaptera novaeangliae*). *Marine Mammal Science* **15**: 1–32.

Spieler, M. and Linsenmair, K.E. 1998. Migration patterns and diurnal use of shelter in a ranid frog of a West African savannah, a telemetric study. *Amphibia-Reptilia* **19**: 43-64.

van de Mortel, T.F. and Goldingay, R. 1998. Population assessment of the endangered Green and Golden Bell Frog *Litoria aurea* at Port Kembla, New South Wales. *Australian Zoologist* **31:** 48-54.

White, G.C. and Burnham, K.P. 1999. Program MARK: suvival estimation from populations of marked animals. *Bird Study* **46**: 120-138.

Wintle, B.A., McCarthy, M.A., Parris, K. M. and Burgmann, M.A. 2004. Precision and bias of methods for estimating point survey detection probabilities. *Ecological Applications* 14: 703-712.

Zimmerman, B.L. 1994. Audio Strip Transects. Pp. 92-97 in *Measuring and Monitoring Biological Diversity: Standard Methods for Amphibians*, edited by W.R. Heyer, M.A. Donnelly, R.W. McDiarmid, L.C. Hayek and M.S. Foster. Smithsonian Institution Press, Washington.